Chapter 6

Riparian Vegetation and Associated Wildlife

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Introduction

In the Western United States, riparian areas are conspicuous as narrow belts of dense, green vegetation along streams and rivers. Fluvial marshes—areas of wetland characterized by emergent herbaceous plants like sedges (*Carex* sp.), grasses (Poaceae family), and cattails (*Typha* sp.)—can be part of the riparian areas that are associated with erosion and sediment deposition patterns of the adjoining stream or river. The riparian and wetland plant community is dependent on surface water and groundwater flows (Busch and Smith, 1995; Stromberg and others, 1996; Stromberg, 2001) and is transitional between aquatic and upland systems. In Grand Canyon, the upland system is characterized by limited moisture and includes Great Basin desertscrub, Mohave desertscrub, and Sonoran desertscrub plant constituents (classifications per Brown, 1982), such as mormon tea (*Ephedra nevadensis*), sagebrush (*Artemisia* spp.), white brittle bush (*Encelia farinosa*), and barrel cactus (*Ferocactus cylindraceus*). The dry uplands are a stark contrast to the lush plant community along the Colorado River in Grand Canyon (figs. 1a–d).

Riparian areas are a junction between aquatic and terrestrial habitat types. In the West, they tend to exhibit higher levels of species diversity, richness, and population densities than either adjacent habitat. Because of these characteristics, riparian areas are of high value to managers, scientists, and the public, particularly to Native American communities (see chapter 11, this report). The importance of riparian areas in the maintenance of biodiversity is well documented (Nilsson and others, 1989; Naiman, 1992; Nilsson, 1992; Decamps, 1993; Lock and Naiman, 1998; Saab, 1999; National Research Council, 2002). Riparian areas are especially important in the Southwestern United States, where more than 50% of 166 species of breeding birds in the lowlands are completely dependent on water-related habitat (Johnson and others, 1977; Farley and others, 1994). Riparian areas also buffer the movement of materials, such as nitrogen and carbon, between aquatic and terrestrial environments and help retain nutrients along the river or stream channel (Schlosser and Karr, 1981; Jacobs and Gilliam, 1985; Naiman and Decamps, 1990). Vegetation along a water course also provides cover and food such as insects and seeds for animal life. In Grand Canyon, whitewater recreationists and hikers also use the shade of riparian shrubs and trees in the hot summer months. Understand-

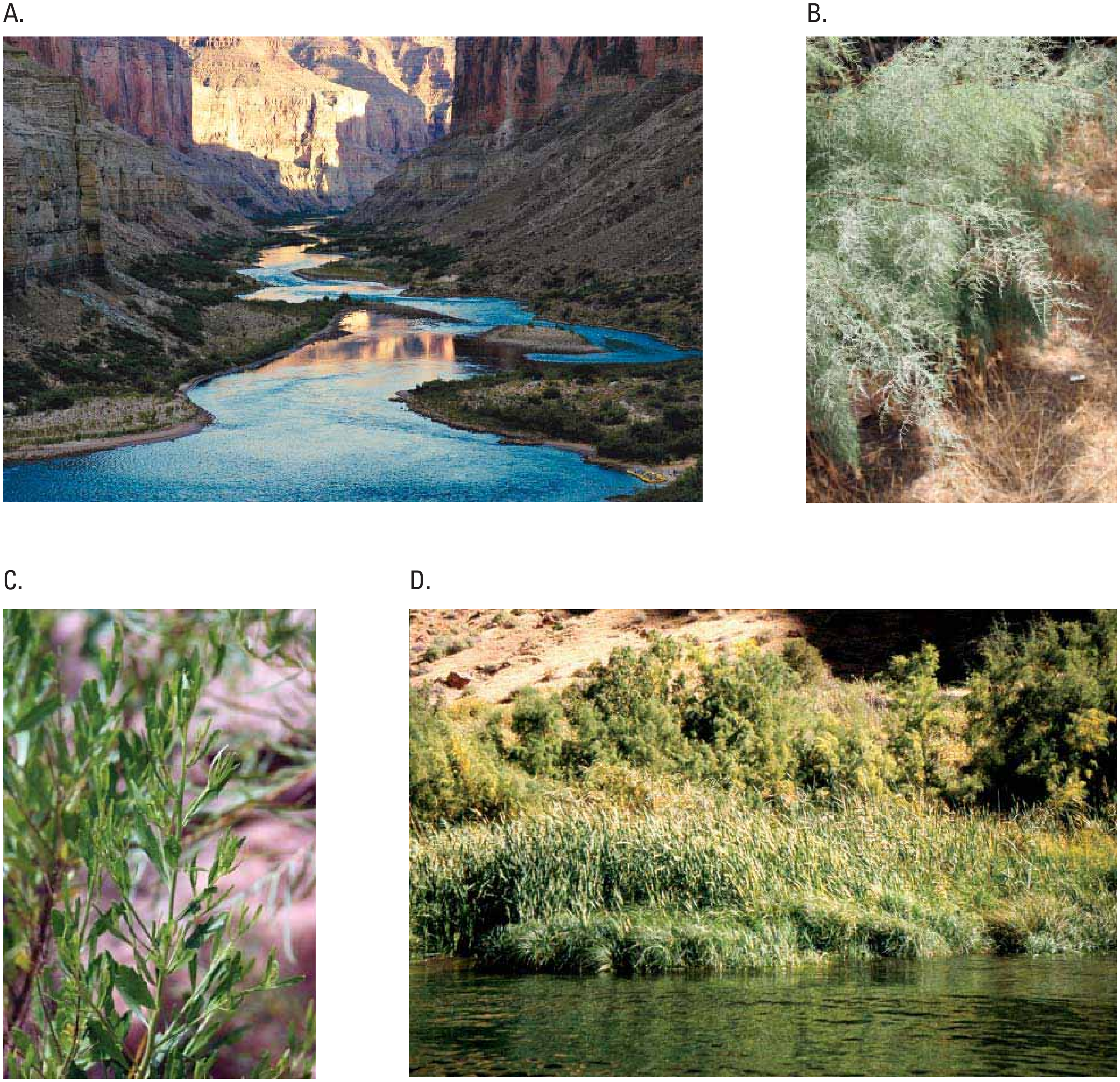


Figure 1. A. Riparian zone along the Colorado River in Grand Canyon. The predam high-water zone is noticeable as a line of vegetation well above the shoreline. Postdam riparian vegetation has progressed downslope and become thicker (photograph © 2005 Geoff Gourley; used with permission). B. Tamarisk (*Tamarix ramosissima*), which is one of the species that was found along the predam high-water zone. Tamarisk was introduced to the Colorado River Basin in the 1880s and was present in Grand Canyon in 1938 (photograph by Jeff Sorensen, Arizona Game and Fish Department). C. Seep willow (*Baccharis* sp.), a new high-water zone constituent. This species was also present before the dam, but in lower densities (photograph by Jeff Sorensen, Arizona Game and Fish Department). D. Examples of fluvial marsh and postdam species. The foreground is composed of common reed (*Phragmites australis*) and water sedge (*Carex aquatilis*), but the background shows tamarisk and arrowweed (*Pluchea sericea*) (photograph by Jeff Sorensen, Arizona Game and Fish Department).

ing how this community has changed over time is key to developing appropriate management strategies for this important resource.

This chapter describes changes in the riparian and fluvial marsh communities along the Colorado River in Grand Canyon from the closure of the Glen Canyon Dam and the beginning of the regulation of the river in 1963 to the present. To provide a better understanding of how dam operations have affected riparian vegetation, we examine changes in Grand Canyon riparian vegetation during three periods of time (1963–80; 1981–91; 1991–present) that correspond to major operational changes at Glen Canyon Dam. The effects on riparian vegetation of both the modified low fluctuating flow (MLFF) alternative, which was implemented beginning in 1996, and the recent drought are discussed. The chapter concludes with a summary of the findings with respect to riparian vegetation as habitat and its relationship to other resources and with a discussion of monitoring priorities within the context of the Glen Canyon Dam Adaptive Management Program.

Background

Predam Vegetation

Much of what is known about predam vegetation comes from the 1938 investigation of the Colorado River corridor by Clover and Jotter (1944). Predam vegetation in the high-elevation benches (fig. 2), the areas well above the river that are less frequently scoured by floods, was dominated by mesquite (*Prosopis glandulosa*), catclaw acacia (*Acacia greggii*), Apache plume (*Fallugia paradoxa*), and tamarisk (*Tamarix ramosissima*). Tamarisk was introduced to the Colorado River Basin in the 1800s and was present in Grand Canyon in 1938 (Clover and Jotter, 1944). These same investigators noted the presence of coyote willow (*Salix exigua*), rabbitbrush (*Chrysothamnus nauseosus*), four-wing salt bush (*Atriplex canescens*), and Goodding's willow (*Salix gooddingii*) along or close to the shoreline (moist sand) at Lees Ferry. On higher benches, they found arrowweed (*Pluchea sericea*) and four-wing salt bush. Mormon tea and rabbitbrush were found in the talus above the flood plain. The presence of plant cover from the river up to the talus at Lees Ferry (RM 0) in 1938 illustrated the degree of community development. Greater vegetation cover may have occurred previously because the 1930s was the period of the lowest discharges in the record (Topping and others, 2003).

Elsewhere in the river corridor, Clover and Jotter (1944) documented patchy riparian development, including the absence of vegetation in the moist sand zone at President Harding Rapids (approximately RM 43.8) (Stevens, 1990) associated with a recent sand deposit. They also noted the existence of marsh emergent species, including cattails and rushes (Juncaceae family).

The predam riparian zone of Grand Canyon was periodically disturbed with floods of variable frequency and magnitude that redistributed sediment of varying grain size and influenced what plants colonized the bare area. Plants like acacia and mesquite located in the high-water zone were disturbed less frequently than were herbaceous and marsh plants located near the lower benches. The riparian assemblage likely represented different stages of maturity and succession as it progressed either landward or downstream from a tributary source of disturbance. At the higher benches, the vegetation would be the most mature and stable, while at the shoreline, the vegetation would be composed of more flood-tolerant pioneering species. Areas from the channel upslope to the former high-water zone (also known as the old high-water zone) were composed of a mix of perennial and annual plants that corresponded with tolerances to moisture and disturbance. (Hereafter, refer to fig. 2 for references that relate discharge to riparian elevations.)

Variables Affecting Vegetation Change

The abundance, distribution, and composition of riparian and fluvial marsh vegetation along the river corridor in Grand Canyon are influenced by many variables including yearly discharge, soils, sedimentation, time since disturbance, and temperature (Turner and Karpiscak, 1980; Baker, 1989; Stromberg and Patten, 1991; Busch and Smith, 1995; Stevens and others, 1995; Stromberg, 2001). A conceptual model illustrates some of the linkages between physical processes and riparian habitat (fig. 3); however, the model shown in figure 3 is not comprehensive with respect to all variables that affect riparian habitat.

Following closure of Glen Canyon Dam in 1963, changes in the hydrologic and sediment regime occurred that affected vegetation in Grand Canyon. The operations reduced annual peak discharge and duration and increased the yearly base flow (Topping and others, 2003). The yearly hydrograph was replaced by monthly volume releases that followed energy demands (high releases in December–February and in July–September) rather than seasonal patterns (high flows occurring

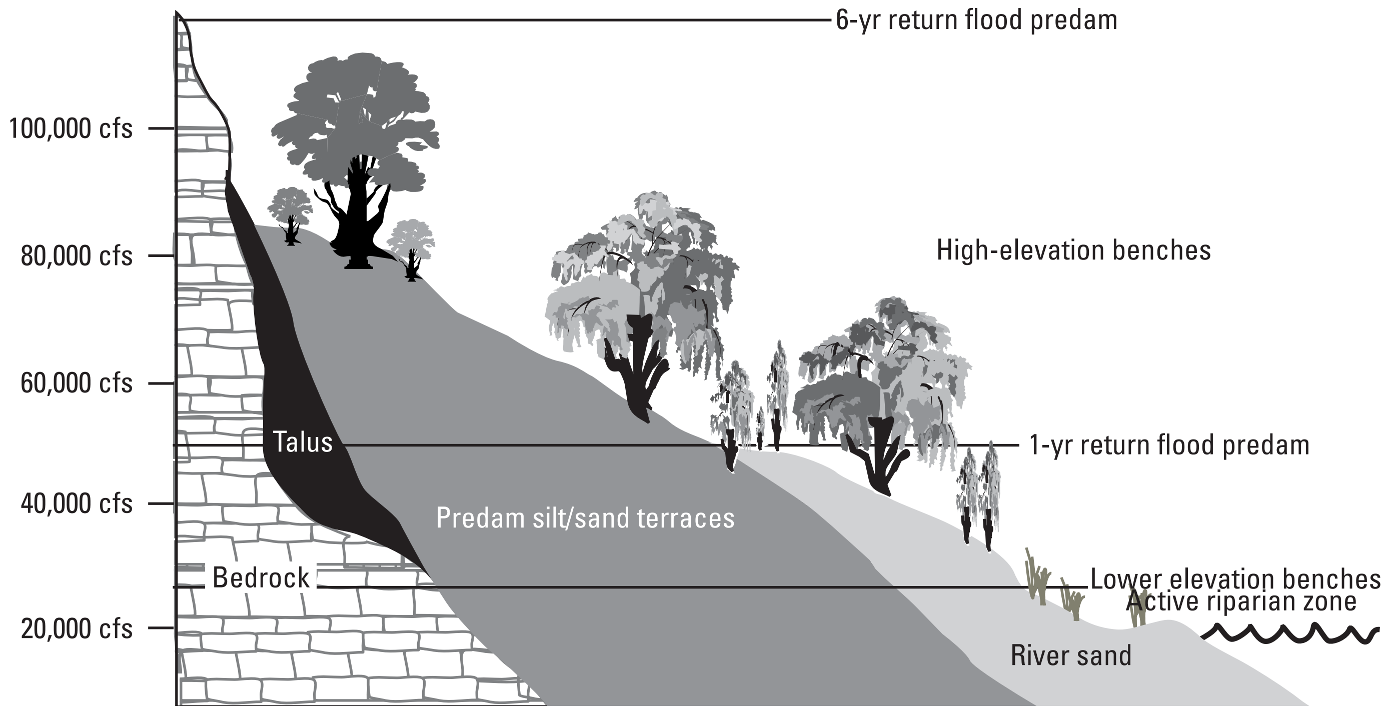


Figure 2. Habitat zones according to inundation frequency and flow magnitude (cubic feet per second). Regulation of the Colorado River by Glen Canyon Dam has resulted in reduced flood frequencies and magnitudes. In the postdam setting, the area below 50,000-cfs water-surface elevation is the active riparian zone. (In the postdam period, the active riparian zone remained at 50,000-cfs water-surface elevation during the 1980s, dropping to 45,000 cfs after 1991, when new restrictions constrained dam operations to minimize resource impacts.) Above the active riparian zone are the higher elevation benches, areas well above the river that are less frequently scoured by floods and were subjected to a predam 6-yr return flood frequency. Within the active riparian zone are bands of vegetation that follow a moisture gradient from water-tolerant plants located near shoreline to species that tolerate drier upslope conditions. Figure modified from Carothers and Aitchison (1976) with data from Topping and others (2003).

in June and July). Postdam median daily discharge increased to 12,600 cubic feet per second (cfs), which was 58% greater than the predam volumes of 7,980 cfs (Topping and others, 2003). Larger average discharges increased sediment-export rates (Topping and others, 2000) and reduced sand storage along channel margins and reattachment bars associated with debris fan-eddy complexes (Schmidt and Rubin, 1995). Both channel margins and reattachment bars are substrates for plant colonization. Higher sediment-export rates were most noticeable in Marble Canyon (Topping and others, 2000). Also, the dam reduced the amount of upstream sediment coming into the river by 99.9% (Topping and others, 2000); tributaries below the dam, including the Paria and Little Colorado Rivers, now provide the bulk of sand and smaller sediment fractions (see chapter 1, this report).

Disturbance frequency along a river or stream is one of several variables that affect riparian community development (Stromberg and Patten, 1991; Bendix, 1994; Toner and Keddy, 1997). Scour and sediment reworking within depositional environments like debris fans, channel margins, and return channels (Schmidt, 1990; Schmidt and Rubin, 1995) provided sites for colonization by marsh and riparian plant species (Clover and Jotter, 1944; Turner and Karpiscak, 1980; Gecy and Wilson, 1990; Decamps, 1993). The pioneer assemblage may be from an introduced seed source or from vegetative regrowth following scour (Gecy and Wilson, 1990). Before regulation of the Colorado River through Glen and Grand Canyons, large portions of the river's flood plain were periodically scoured. Predam 1-yr return flood discharge reached approximately 50,000 cfs, with larger discharges of 120,000 cfs occurring every 6 yr on average (fig. 2) (Topping and others, 2003). Yearly flooding reduced vegetation below the 50,000-cfs water-surface elevation, while larger, less frequent floods affected vegetation communities on higher benches. Lower peak flows caused by Glen Canyon Dam allowed species, including nonnative plants, to occupy lower flood-plain

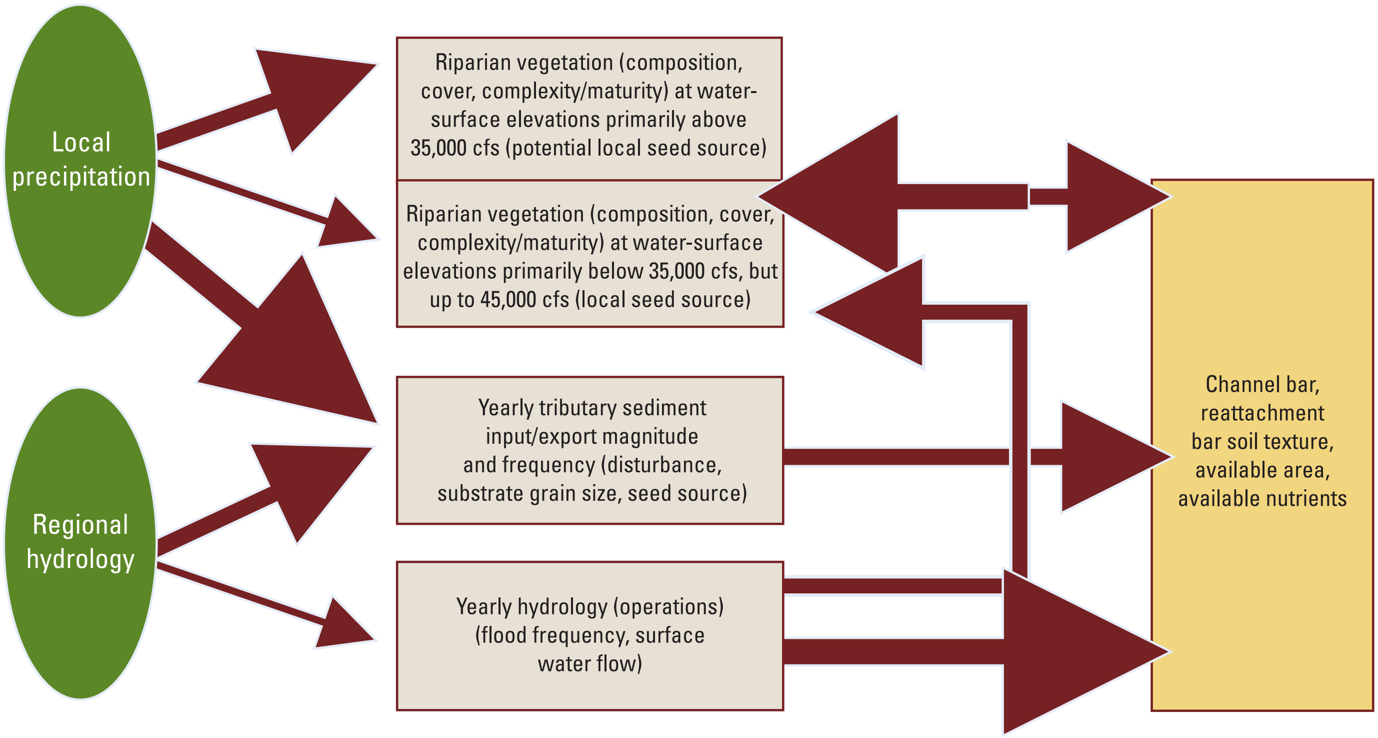


Figure 3. A conceptual model of physical factors that affect riparian vegetation development along the river corridor. Thicker arrows indicate a greater degree of effect on riparian vegetation. The closure of Glen Canyon Dam and the beginning of flow regulation of the Colorado River through Grand Canyon in 1963 all but eliminated the mainstem sand supply to Grand Canyon. Also, dam operations are now independent of tributary inputs of sediment. Taken together, dam-induced changes in both sand supply and flow have altered the sedimentary processes that provide substrate for riparian vegetation.

benches. Riparian areas are particularly prone to invasion by nonnative plants because they are frequently disturbed by flood events, which create favorable conditions for the seeds of nonnative plants that can be dispersed long distances by a variety of processes (Decamps, 1993).

Status and Trends

Riparian community changes following the closure of Glen Canyon Dam in 1963 occurred over three periods.

Period I: Initial Vegetation Expansion (1963–80)

Immediately following the closure of Glen Canyon Dam, operations focused on filling Lake Powell, delivering water to Lake Mead, and producing peak power. Discharges were reduced to between 1,000 and 20,000 cfs during this period (median discharge was 9,490 cfs in the 1960s). A series of discharges of 50,000 cfs conducted in 1965 cleaned the channel below the dam and raised the elevation of Lake Mead (Topping and others, 2003). Daily fluctuations in the 1970s were large, varying between 4,000 and 25,000 cfs, with a median discharge of 11,600 cfs (Topping and others, 2003). The result of dam operations during this period was to encourage plant colonization along the channel in the low-elevation benches.

Vegetation expansion below the 50,000-cfs water-surface elevation was documented by Turner and Karpiscak (1980), who used repeat photography from historical expeditionary trips through Grand Canyon such as J.W. Powell's second trip in 1872 (Darrah, 1948), the Robert Stanton expedition in 1889 (Stanton, 1965), and the U.S. Geological Survey expedition in 1921 (LaRue, 1925). Although Turner and Karpiscak (1980) did not quantify vegetation change, they did qualitatively demonstrate an increase in vegetation in the postdam fluvial sediment zone (up to 30,000 cfs) and in the predam fluvial sediment zone (30,000–85,000 cfs; 2-yr return period) (Topping and others, 2003). They noted dense stands of tamarisk, coyote willow, and arrowweed throughout the corridor, with desert broom (*Baccharis sarothroides*), Bermudagrass (*Cynodon dactylon*), Emory seep willow (*Baccharis emoryi*), and some cottonwoods (*Populus fremontii*) along the postdam fluvial zone. The expansion of coyote willow, tamarisk, and arrowweed within the predam and postdam fluvial zones was predictable given the creation of a stable water source and exposed land area (figs. 4a and b). The expansion of emergents such as cattails along the channel was also noted by Turner and Karpiscak (1980). The higher bench (land above >50,000 cfs) was found to be changing at a slower rate and composed of predam high-bench species like acacia, mesquite, sand dropseed (*Sporobolus cryptandrus*), and Apache plume.

The qualitative findings of Turner and Karpiscak (1980) are consistent with a land area change study of selected sites in Marble Canyon and upper Grand Canyon through the use of geographic information systems (Waring, 1995). Waring estimated a 100% increase in vegetation in the postdam and predam fluvial sediment zones between 1965 and 1973 (56.5 acres vs. 108.6 acres (228,503 m^2 vs. 439,420 m^2)). Anderson and Ruffner (1988) examined the predam high-bench terrace vegetation and determined that this zone showed little recruitment of new acacia or mesquite individuals. In other words, this zone was not showing signs of replacement of similar species. They hypothesized that the vegetation was becoming more mature, with individuals becoming larger and more closely spaced. Over time, the vegetation in this zone would become less dense as mature individuals died and were not replaced. Species found in this predam bench would "move shoreward" over time.

Period II: Inundation and Habitat Reworking (1981–90)

In 1980, Lake Powell reached full pool elevation, and operations over the next decade focused primarily on water delivery and power generation. Because the early 1980s was a wet period, causing a high-release spill of 97,000 cfs in June 1983 (Martin, 1989), however, Glen Canyon Dam was also operated to manage spring inflows and protect the integrity of the dam. As a result, the 1980s produced several years of releases greater than 20,000 cfs for portions of the year (U.S. Geological Survey, 2005), with higher releases occurring in spring to reduce the frequency of spills. Median discharge for the decade was 15,900 cfs (Topping and others, 2003), approximately 32% greater than the median releases of the 1970s. Fine-sediment erosion and export from the Marble Canyon and upper Grand Canyon reaches occurred in this decade (Topping and others, 2000; Schmidt and others, 2004). Sediment export exceeded inputs during these events, resulting in an overall loss of sediment in the system.

The higher peak and median discharge presented situations of sustained inundation of riparian vegetation along the channel and increased water-table elevations that promoted expansion of woody vegetation in this decade (figs. 4b and c). The peak flow likely redistributed seeds from the predam flood-plain surfaces, which may have promoted establishment and growth of acacia and mesquite within the lower elevation benches. Waring (1995) detected a 13% decrease in vegetation occupying area below 50,000-cfs discharge. Waring showed an increase in vegetated area in the higher elevation benches for 1984 compared with 1975; measurements of mesquite in the predam flood plain by other researchers, however, did not indicate a growth response to the flood events of the 1980s (Anderson and Ruffner, 1988).

Period III: Low Fluctuating Flows and Experimentation (1991-present)

River Flows

The operation of Glen Canyon Dam since 1991 has focused on meeting water allocation requirements, producing power, and complying with environmental constraints designed to minimize the effects of Glen Canyon Dam on the erosion of recreational and archaeological sites and on the deterioration of habitats for endangered species, particularly humpback chub (*Gila cypha*) (U.S. Department of the Interior, 1995). During this period, flows have been further stabilized, not varying more than 8,000 cfs daily, though median annual flows have decreased only 15% when compared with those of the 1980s (13,500 cfs vs. 15,900 cfs) (Topping and others, 2003). The frequency of high peak flows has diminished with two experimental high-flow events of 41,000 cfs and 45,000 cfs occurring in November 2004 for 2.5 d and in March 1996 for 7 d (Webb and others, 1999). As a result, since 1991 the active riparian zone has been reduced to 45,000-cfs water-surface elevation. Smaller, shorter duration spikes of up to 31,000 cfs occurred in

A.

B.

C.

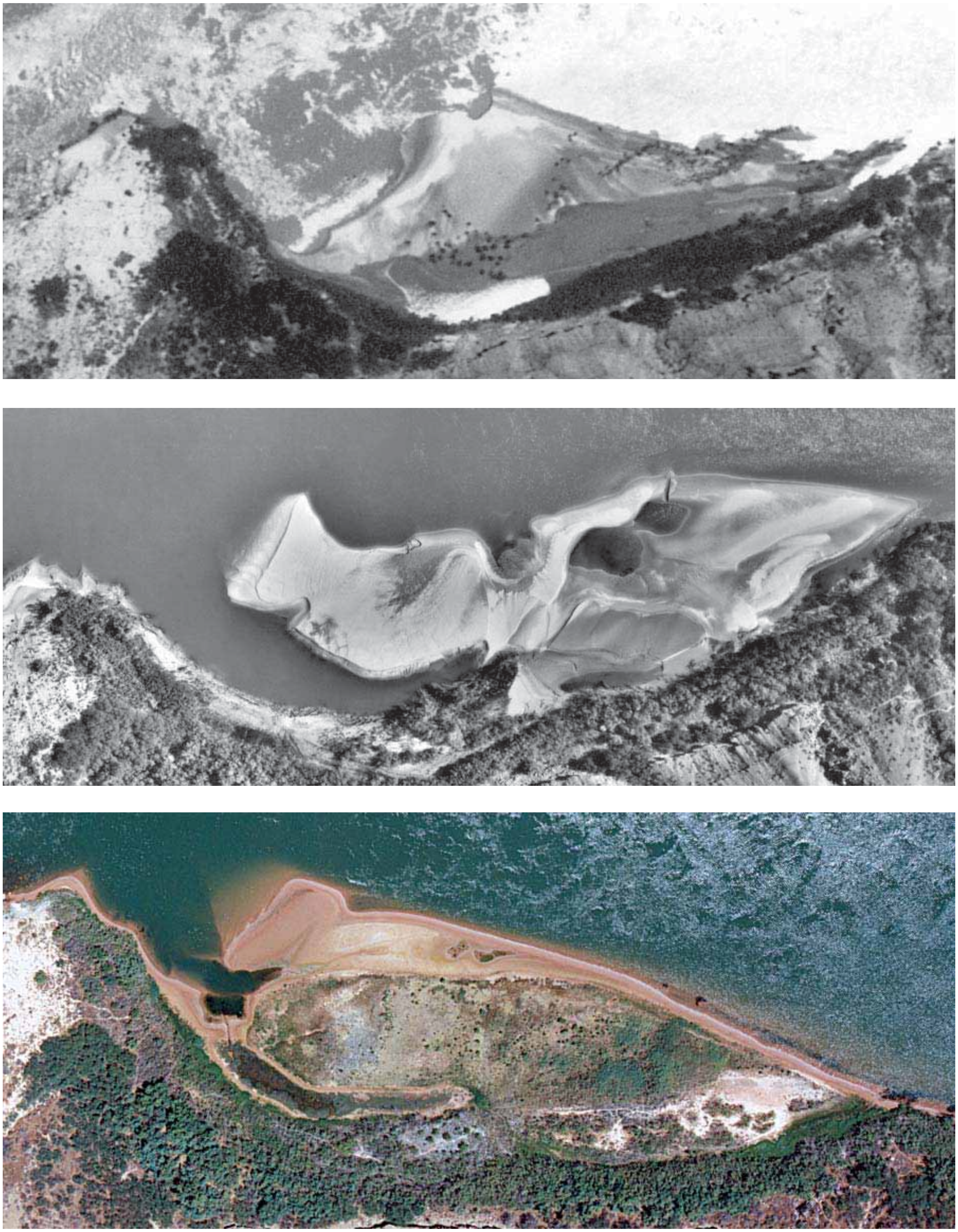


Figure 4. A. Aerial photograph from 1965 at RM 55.4 showing sparse vegetation occupying the sandbar and beginning to expand into the postdam fluvial zone. B. Aerial photograph from 1984 of RM 55.4 showing effects of flooding, which scoured low-lying riparian habitats. Vegetation occupies larger expanses along the shoreline and upslope from the river. C. Aerial photograph from 1994 of RM 55.4 showing expansion of riparian and marsh vegetation since 1984 on the sandbar and along the shoreline (source: U.S. Geological Survey file photographs).

1997 and 2000 (Schmidt and others, 2004). Peak flows (flows >120,000 cfs) have also been reduced by more than 50% of mean long-term high flows experienced before 1963 (Topping and others, 2003). As a result, the active riparian zone in Grand Canyon has contracted in width to that area below approximately 50,000-cfs water-elevation stage, with greatest change occurring below 30,000 cfs. The higher elevation bench (>50,000 cfs) persists through yearly rainfall events and is little affected by operations compared to predam hydrology.

Response in the Plant Community

This 14-yr period of stable but fluctuating flows and experimentation resulted in the expansion of vegetation into open areas, including into campsites and channel margins within the active riparian zone (Kearsley and others, 1994; Webb and others, 2002); the reduction of marsh habitat associated with eddy return channels (i.e., backwaters) (Stevens and others, 1995; Goeking and others, 2003); and most recently (since 2002), a reduction of vegetative cover in low channel positions (Kearsley, 2004b). The community as a whole has become more mature, providing complex habitat for riparian breeding birds. With the onset of the drought in 2000 there has also been a reduction in cover of annual and perennial grasses in areas located above flows of 35,000-cfs elevation (Kearsley, 2004b).

Forty-one percent of camping sites surveyed between 1983 and 1991 were determined to be unusable because of vegetation overgrowth (Kearsley and others, 1994). Vegetation expansion into campsites occurred in reaches that are classified as wide reaches (Schmidt, 1990) or in areas where more sediment is available for plant establishment. Kaplinski and others (2005) discussed trends in vegetation expansion into campsites since 1991; their findings are summarized in chapter 12 of this report. Vegetation expansion between the high-water periods of 1984 and 1992 was supported by Waring (1995), who showed expansion during this period at a percentage of change similar to that which occurred with initial dam closure through 1973. Waring (1995) speculated that the rate of vegetation expansion increased during the early 1990s with the implementation of interim operating criteria. Expansion within the zone between shoreline and up to the 50,000-cfs water-surface elevation included the establishment by nonnative plants and pioneer species like camel thorn (*Alhagi maurorum*) and clonal growth by woody vegetation, including arrowweed and coyote willow. This vegetation expansion resulted in an increase in riparian bird habitat (see chapter 7, this report). Vegetation expansion was greatest in channel margin habitats used primarily by wildlife and was least in sites adjacent to rapids associated with debris fans where disturbance was more likely to occur (Melis and others, 1995; Waring, 1995; Webb and others, 2002).

Debris fan-eddy complexes (Schmidt and Rubin, 1995) are geomorphic features that support fluvial marsh habitat, primarily because they are low-velocity habitats that accumulate silt and clay fractions (Schmidt and Rubin, 1995; Stevens and others, 1995). Daily inundation frequency, soil texture, and distance from the dam influence marsh locations and assemblages (Stevens and others, 1995). Wet-marsh constituents like cattails, sedges, and common reed (*Phragmites australis*) are found in sites with increased inundation frequency, while drier marsh-associated species like tamarisk, arrowweed, horsetails (*Equisetum* sp.), and willows (*Salix* sp.) are associated with lower inundation frequencies. Interim operating criteria, initiated in 1991 and followed by the MLFF alternative in 1996, reduced inundation frequency. This change is coincident with a reduction in wet-marsh habitat since 1991 (Stevens and others, 1995; Kearsley and Ayers, 1996).

Geomorphic Effects

The effect of geomorphology on plant assemblages is illustrated in marsh plots that were surveyed in the mid-1990s. Narrow reaches of the river such as that of Marble Canyon experienced losses of marsh patches, which correspond to a reported loss of sediment in this reach during the same time (Kearsley and Ayers, 1996; Schmidt and others, 2004). Wider reaches found near the Little Colorado River and in western Grand Canyon that have greater sediment-storage capacities showed gains and losses of marsh patches during these same years in the mid-1990s. The variability in the number of patches within these reaches may reflect local sediment inputs from ungaged tributaries as well as inputs from the Little Colorado River. For these same years, a drying trend (i.e., plants encountered were associated with lower moisture gradients) was noted for riparian plants (Kearsley and Ayers, 1996). Reduced numbers of marshes support a hypothesis that interim flows reduced inundation frequency and that species encountered were more likely to be associated with a lower moisture gradient. Alternatively, the change may reflect infilling and riparian community succession. Marsh census numbers since 1995 are not available, but geomorphic studies of debris fan-eddy complexes detected reduction in backwaters from 1984 to 2000 (Goeking and others, 2003). A reduction in these sites may be an indication that fine-sediment habitats were also declining during this period. Sediment export, particularly silt and clay, and reduced fluctuations likely reduced the area of cover represented by wet-marsh species in the 1990s through 2001.

Hydrology and Climatic Influences

Reservoir levels, yearly operations, and local precipitation affect riparian vegetation growth and development within all vegetation zones along the river corridor. A persistent, basinwide drought was identified in July 2000 by the National Drought Mitigation Center (www.drought.unl.edu/dm/archive/2000/drmon0725.htm, accessed February 8, 2005). Since then, inflows to Lake Powell have been below average, leading to drawdown of both Lake Powell and Lake Mead (see chapter 4, this report). As a result, Glen Canyon Dam has released the minimum amount of water needed to meet delivery requirements, which is 8.23 million acre-feet (10,148 million m^3). While overall volume of delivery has been reduced, monthly median flows have not changed appreciably. Beginning in 2002, the months from January to March and from June to August are dominated by power-generation flows in summer months and fish suppression measures in winter months (U.S. Department of the Interior, 2004a). Fluctuations vary from 5,000 to 20,000 cfs daily in the winter months and by 8,000 cfs daily in summer, with base flow being approximately 10,000–12,000 cfs. Other months have lower volumes allocated with corresponding lower base flow and reduced daily range (e.g., 5,000–10,000 cfs in April). The abrupt shifts in monthly volumes in April and September expose areas in spring for plant establishment but are soon followed by high summer fluctuations in June. By September, the area inundated to 17,000-cfs water-surface elevation is often sparsely vegetated and reduced in sediment (Kearsley, 2004b). Precipitation variability and operational shifts of Glen Canyon Dam resulted in continued changes in the vegetation cover, abundance, and density along the river corridor.

Recent Monitoring Results

Between 2001 and 2003, riparian vegetation was affected both by changes in dam operations and by a persistent drought. The summers of 2002 and 2003 had higher daily minimum flows than 2001, and these years also had winter (January to March) discharges that varied from 5,000 cfs to 20,000 cfs. Vegetation volume (a surrogate for structure) in the active riparian zone (5,000 cfs to 45,000 cfs) responded markedly each year. Between 2001 and 2002 volume decreased by 15% but had recovered by approximately the same amount between 2002 and 2003 (fig. 5) (Kearsley, 2004a). The recovery was attributable to the operational change that took place in January 2003. How these volumes may influence riparian bird density or abundances between years is not known. In contrast, vegetation at higher water-surface elevations (>45,000 cfs) changed little between years (fig. 5) (Kearsley, 2004a). Vegetation at higher water-surface elevations may respond more to localized precipitation events than to dam operations (Kearsley, 2004a). In general, operations had the greatest effect on vegetation located below the 35,000-cfs water-surface elevation.

Measures of plant abundance, species richness, diversity, and distribution all showed a decline since 2001 (Kearsley, 2004b). Operations and local precipitation differentially affected plants along the elevational gradient. Herbaceous annuals and perennials like cheat grass (*Bromus tectorum*), sand dropseed, and spiny aster (*Chloracantha spinosa*) located above 35,000-cfs water-surface elevation were affected by yearly precipitation and showed the greatest decline in cover (fig. 6a). The effect of the drought on higher elevation plants was also evident when species composition was examined. Species richness changed significantly at sites at 45,000 cfs and 60,000 cfs (fig. 6b) (Kearsley, 2004b); the change was associated mostly with a loss of annual and rarely encountered plant species. Increased summer precipitation in 2003 was responsible for increases in species richness in both of these elevations (fig. 6b). Annuals appearing in wetter years likely contributed to these increases (Kearsley, 2004b). Compositional shifts did not

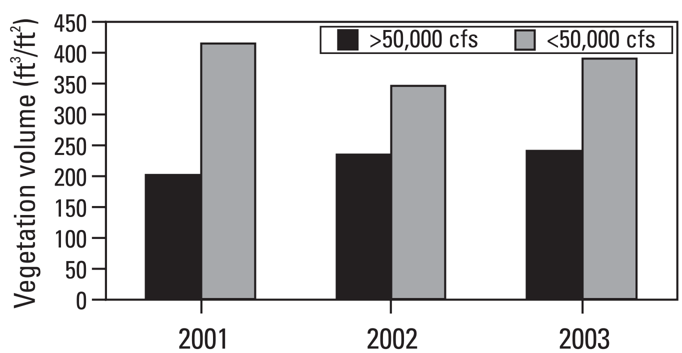


Figure 5. Change in vegetation volume (a surrogate measure of structure) from 2001 to 2003 in the riparian zone along the Colorado River in Grand Canyon at surface-water elevations above and below 50,000-cfs surface elevation. Figure modified from Kearsley (2004a).

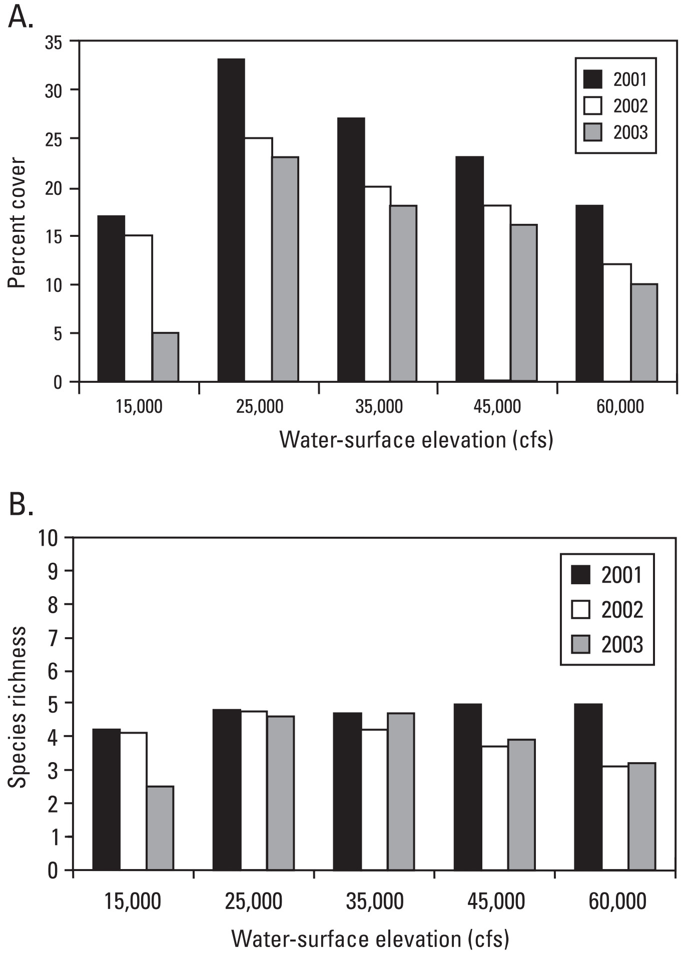


Figure 6. A. Percent change in vegetation covers at five water-surface elevations (cubic feet per second) between 2001 and 2003 in the riparian zone along the Colorado River in Grand Canyon. Cover has declined in all zones since 2001. Discharge had the greatest effect on species richness at water-surface elevations from 35,000 cfs to 15,000 cfs. Overall vegetation cover within the riparian zone is not dense although cover is greatest at the 25,000-cfs water-surface elevation, which corresponds with areas used by campers and breeding birds. Figure modified from Kearsley (2004b). B. Species richness in five water-surface elevations (cubic feet per second) from 2001 to 2003 and change between years in the riparian zone along the Colorado River in Grand Canyon. Species richness is a measure of the total number of species found at each water-surface level and is an indication of biodiversity. Species richness in this case is measured from a scale of 0 to 10 with 10 being the highest amount of richness. Overall species richness within the riparian zone is greatest in those zones that are above the 25,000-cfs water-surface elevation where vegetation is not directly scoured by flow. Species richness in the upper water-surface elevations is more affected by yearly precipitation. Species at upper surface water elevations have declined since 2001 because of drought conditions and include annual cheat grass (*Bromus tectorum*) and perennial sand dropseed (*Sporobolus cryptandrus*). Figure modified from Kearsley (2004b).

occur for zones below 35,000 cfs, and these data, in combination with vegetation volume measurements, suggest that changes in this zone were associated with increased growth of established woody species rather than with recruitment or mortality. Moreover, reductions in cover, richness, and diversity in lower water-surface elevation locations (<25,000 cfs) were caused by sediment loss, inundation, or scour that coincided with operational changes in January 2003. Dam operations influenced changes in vegetation beyond recorded discharge levels, possibly up to approximately 15,000 cfs, while local precipitation appeared to have a greater influence, in the short term, on vegetation above the 35,000-cfs water-surface elevation.

Since the 1990s, reservoir levels, yearly operations, and local precipitation have affected riparian vegetation growth and development along the river corridor in Grand Canyon (figs. 3, 5, and 6). Though other factors do affect riparian vegetation dynamics, these variables appear to be significant drivers in riparian vegetation development and change. The riparian zone in Grand Canyon has contracted shoreward as flows have stabilized. Riparian vegetation at water-surface elevations up to about 15,000 cfs above daily maximum discharge responds to operational changes. Vegetation below a water-surface elevation of 45,000 cfs has become denser and has expanded into open sites, including campsites. Vegetation cover and richness at low water-surface elevation locations (below 20,000 cfs) are most directly affected by dam operations. The fluvial marsh community is the most responsive of vegetative communities within Grand Canyon to changes in hydrology and sediment supply. Not surprisingly, cover and richness decline during flow fluctuations that promote scour and sediment export (Kearsley, 2004b). At the same time these flows can increase inundation frequency at higher elevations and can shift plant composition to more water-tolerant species like cattails and rushes as a result of annual changes in operations (Stevens and others, 1995). Essentially, the riparian area has declined quantitatively in some aspects (less spatial coverage, fewer numbers of species) and has changed qualitatively (denser, more mature).

Riparian Vegetation as Terrestrial Habitat

As stated in the Introduction of this chapter, riparian communities in the Southwestern United States play an important role as wildlife habitat (Carothers and Brown, 1991; Farley and others, 1994; Skagen and others, 1998; Stevens and Ayers, 2002). Along the Colorado River, riparian birds have had a greater emphasis placed on them than other types of wildlife in terms of monitoring and are treated in a separate chapter of this report (chapter 7). Wildlife other than endangered species and birds has not been emphasized to date in the Glen Canyon Dam Adaptive Management Program. For these reasons, the following section addresses threatened and endangered species that occupy riparian habitat marshes and springs within the Colorado River ecosystem. Other faunal constituents are briefly mentioned.

Threatened and Endangered Species

Kanab Ambersnail

The Kanab ambersnail (*Oxyloma haydeni* ssp. *kanabensis*) is a terrestrial succineid snail (fig. 7) associated with wetland and spring vegetation on the Colorado Plateau. The snail was listed as endangered in 1992 (England, 1992). Presently, the species is found at three locations: Vaseys Paradise and Elves Chasm (a translocated population), in Grand Canyon National Park, and private land in southern Utah. Data presented here pertain to the snails located at Vaseys Paradise.

Figure 7. Kanab ambersnail (*Oxyloma haydeni* ssp. *kanabensis*), which is monitored at Vaseys Paradise (photograph by Roy Averill-Murray, Arizona Game and Fish Department).

Vaseys Paradise (figs. 8a–c) is a small patch of spring-fed riparian vegetation at RM 31.8 (Stevens, 1990). Ambersnails are found in the vegetation, usually associated with cardinal monkeyflower (*Mimulus cardinalis*) (fig. 8b), watercress (*Rorippa nasturtium-aquaticum*) (fig. 8c), and water sedge (*Carex aquatilis*). Ambersnail adults overwinter and reproduce in spring. Recruitment into the adult population takes place during summer and fall (Stevens and others, 1998; Nelson, 2001).

Habitat

The greatest gains in habitat area, measured by traditional land-survey methods, occurred between fall 2001 and fall 2002 when snail habitat at Vaseys Paradise increased 23% in area (~2,374 ft² vs. ~3,103 ft² (220.6 m^2 vs. 288.4 m^2)) (fig. 9a) (U.S. Geological Survey, unpub. data, 1998–2004). Increases in measured habitat may be attributable to low minimum flows in 2001 that increased area for colonization by watercress, monkeyflower, or other plants; however, watercress, which is a species adapted to disturbance and that requires sustained moisture, has decreased since 1998 because spring discharges declined in association with the drought. At the same time, monkeyflower increased (U.S. Geological Survey, unpub. data, 1998–2004) and accounted for most of the habitat increase measured between fall 2001 and fall 2002. Monkeyflower, while still requiring moisture, appears to be more tolerant of drier habitats. Water sedge is patchily distributed in Kanab ambersnail habitat and is a source of forage for bighorn sheep (*Ovis canadensis*). As a site that provides a reliable source of vegetation in a drought, the springs are now habitually visited by bighorn sheep, resulting in vegetation used by the snails being regularly trampled.

Snail Abundances

The number of snails has not changed significantly since 1998. Fall numbers generally exceed spring numbers as would be expected with seasonal recruitment (fig. 9b; U.S. Geological Survey, unpub. data, 1998–2004). Curiously, while habitat has increased, snail numbers have not had a correlated increase. The lack of increase in snail numbers may be associated with soil moisture, shifts in plant-species composition, and mortality associated with trampling by bighorn sheep rather than with the amount of habitat available.

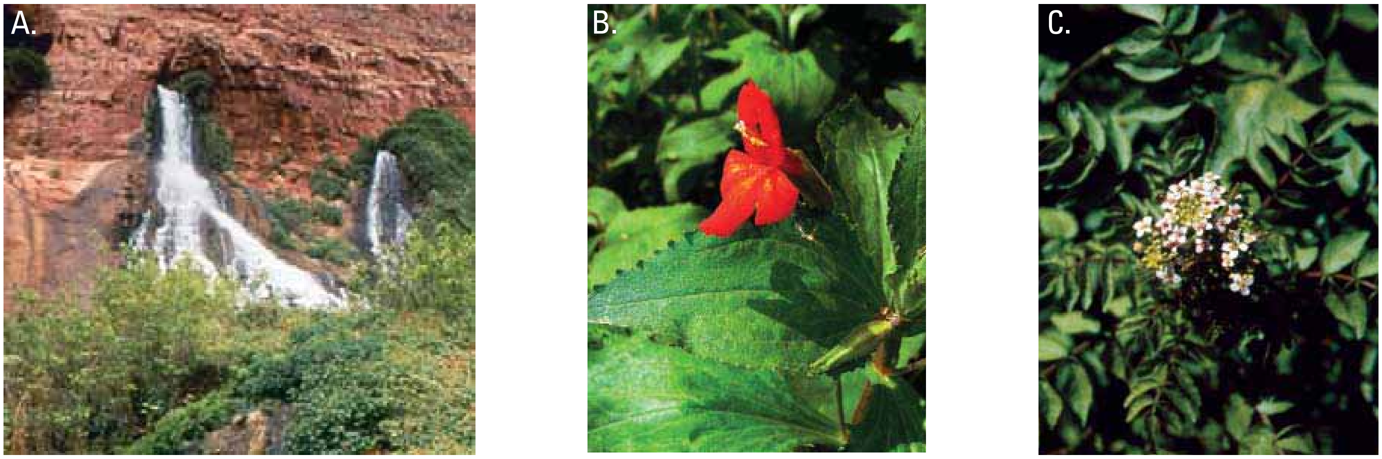


Figure 8. A. Vaseys Paradise along the Colorado River, which is one of three locations known to support the endangered Kanab ambersnail (*Oxyloma haydeni* ssp. *kanabensis*). Cardinal monkeyflower (*Mimulus cardinalis*) (B) and watercress (*Rorippa nasturtium-aquaticum*) (C) are primary plant species associated with Kanab ambersnail (photographs by Jeff Sorensen, Arizona Game and Fish Department).

Other Wildlife

Invertebrates

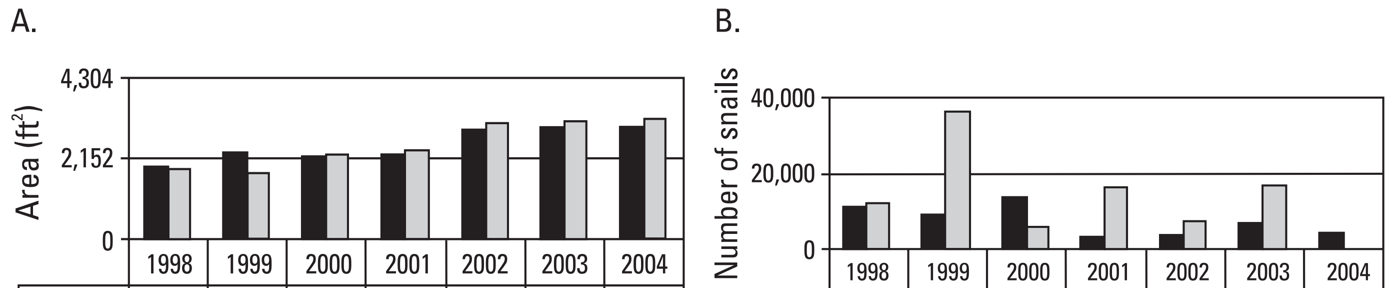
Invertebrate species, as in other ecosystems, account for the greatest number of species found along the river. There are several thousand invertebrate species from over 200 families (Stevens and Ayers, 2002; Lightfoot and others, 2004), including scorpions, spiders, flies, ants, moths, and butterflies. Surveys for invertebrates conducted over the past several years identified either range extensions for species (e.g., butterflies: Arizona powdered-skipper (*Systacea xampa*), piute agave skipper (*Agathymus alliea piute*), desert marble (*Euchloe lotta*), and desert elfin (*Callophrys fotis*)) or species not previously known to exist (e.g., moth, *Schinia immaculate*) (Stevens and Ayers, 2002; Pogue, 2004). Invertebrate composition associated with higher elevation riparian vegetation consists largely of native invertebrate taxa, while the lower elevation riparian vegetation includes a mix of native and nonnative invertebrate species (Lightfoot and others, 2004). The mix of species is not unexpected because vegetation in this area consists of a more pronounced mix of native and nonnative plants.

Amphibians, Mammals, and Reptiles

Surveys for mammals, reptiles, and amphibians have been sporadic (Carothers and Aitchison, 1976; Warren and Schwalbe, 1986; Frey, 2003). Past surveys found 14 mammal species, 16 reptile species, and 4 amphibian species along the corridor. Amphibians of special concern are detailed in the accompanying text box. Only the deer mouse (*Peromyscus maniculatus*) is restricted to the riparian zone (Frey, 2003; U.S. Department of the Interior, 2004b). Larger mammals include beavers (*Castor canadensis*), coyotes (*Canis latrans*), bighorn sheep, mule deer (*Odocoileus rafinesque*), mountain lions (*Puma concolor*), and bobcats (*Lynx rufus*) (U.S. Department of the Interior, 2004b). Mountain lions and bobcats are seen infrequently. Of these mammals, beavers appear to have expanded their numbers since the 1960s (Carothers and Brown, 1991) in association with riparian vegetation expansion. Beavers appear to be relatively evenly distributed throughout the river corridor (U.S. Department of the Interior, 2004b).

Discussion and Future Research Needs

A long-term data set associated with changes in riparian vegetation is lacking for the Colorado River ecosystem. The data that are provided here are results associated with specific research questions of 2- to 3-yr duration rather than monitoring to detect trends. Trend detection associated with riparian vegetation requires local and regional scale monitoring because local and regional hydrology and geomorphology affect the riparian zone. The long-term goal for monitoring in the



A.

	1998	1999	2000	2001	2002	2003	2004
■ Spring	1267.5	2320.9	2187.5	2274.7	2905.2	2984.8	2952.5
□ Fall	1891.6	1752.8	2269.3	2373.7	3103.2	3118.3	3196.8

B.

	1998	1999	2000	2001	2002	2003	2004
■ Spring	10,953	8,667	13,438	3,124	3,745	6,787	4,147
□ Fall	11,921	35,973	5,582	16,052	7,444	16,400	

Figure 9. A. Change in the area of Kanab ambersnail (*Oxyloma haydeni* ssp. *kanabensis*) habitat (ft^2) at Vaseys Paradise from 1998 through 2004 from spring and fall surveys. B. Estimated snail abundances at Vaseys Paradise from 1998 through spring 2004 from spring and fall surveys at Vaseys Paradise (U.S. Geological Survey, unpub. data).

Colorado River should be to use yearly data on cover, species richness, and diversity in concert with semi-decadal vegetation mapping data to discern operational versus climatic effects on the riparian vegetation. Large-scale trend detection at the reach or regional scale will be able to provide information about changes in vegetated area, increases and decreases in vegetation patches, and the vegetation classes that have changed the most. The mapping data can also be integrated with bird monitoring, and other faunal resource monitoring that may be developed, to produce information about habitat quality. Habitat quality affects invertebrate communities that are food resources for both riparian breeding birds and fish communities along the river corridor.

Linkages among vegetation, faunal assemblages, and habitat quality are needed before comprehensive assessments of the riparian zone for the Colorado River can be made. One step toward a comprehensive assessment has been initiated by an inventory of invertebrates along the corridor. The intent of the inventory is to determine what types of invertebrates exist along the corridor, whether or not any species can be used to indicate environmental conditions, and in what quantities these potential indicators occur. Both quantity and type of invertebrates encountered are affected by vegetation assemblages. The challenge associated with riparian vegetation is to determine how dam operations affect plant species assemblages and densities, which, in turn, influence habitat quality and food resources for vertebrates found along the river corridor.

In the long term, continued loss of sediment along the shoreline and changes in the size fraction of the substrate will reduce available colonizing substrate and affect subsequent species establishment (i.e., marsh communities may shift to constituents that persist in coarser substrates) (Stevens and others, 1995). At elevations above the 20,000-cfs flow but still in the active riparian zone, woody vegetation is becoming more mature and less diverse in association with the reduction in high flow frequency. Under current operations (modified low fluctuating flows), precipitation affects vegetation above the 35,000-cfs water-surface elevation more than operations do (Kearsley, 2004 a, b). Remnants of the predam high-water riparian zone have remained relatively unchanged, depending on seasonal precipitation rather than on yearly hydrology for its maintenance. Implications for these changes within the river corridor include the potential reduction in numbers of some riparian bird species that depend on wetter marsh-plant species for nesting or food resources, though other riparian bird species may benefit from the more mature, dense habitat (Anderson and Ohmart, 1984; Farley and others, 1994). Furthermore, continued loss of campsite area associated with vegetation expansion may occur. The trade-offs between recreation and wildlife habitats are value-based management decisions that the adaptive management program will have to address. Some of these trends could be ameliorated through higher frequency disturbances up to and above 45,000-cfs discharges, but these events should be timed to coincide with sufficient sediment inputs and existing system supply.

Declining Riparian Species: Leopard Frogs in Grand Canyon and Glen Canyon

Charles Drost

Figure 1. Northern leopard frog (*Rana pipiens*) (photograph by Charles Drost, U.S. Geological Survey).

Amphibians have been relatively neglected in studies of plants and animals and of the effects of dams in Grand and Glen Canyons. Amphibians were surveyed along the Colorado River in Glen Canyon before the construction of Glen Canyon Dam (Woodbury, 1959), but extensive surveys were not conducted in Grand Canyon until well after the completion of the dam (e.g., Aitchison and others, 1974; Suttkus and others, 1976). Over the last 15 yr there has been increasing recognition and concern about declines in amphibian populations in areas throughout the world (Wyman, 1990; Wake, 1991; Vial and Saylor, 1993). The cause of many of these declines is unknown, but they have even occurred in national parks and other protected areas, suggesting that causes are widespread regional ones (Blaustein and Wake, 1990). We describe here the current status of amphibians in the Colorado River corridor of Grand Canyon National Park and Glen Canyon National Recreation Area based on extensive surveys conducted over the last 10 yr throughout Glen and Grand Canyons, from the uppermost end of Lake Powell to the upper end of Lake Mead.

Surveys found healthy, widespread populations of two species of toads (Woodhouse's (*Bufo woodhousii*) and red-spotted (*B. punctatus*)); the canyon treefrog (*Hyla arenicolor*); and the tiger salamander (*Ambystoma tigrinum*). Northern leopard frogs (*Rana pipiens*) (fig. 1), on the other hand, have declined substantially, paralleling losses reported in other areas of western North America. Leopard frog populations have disappeared from 70% of sites where they were formerly found and have declined in numbers at some sites where they still occur (fig. 2). Some of the losses are of riverside populations in Glen Canyon, which were inundated by Lake Powell (Drost and Sogge, 1993); however, other populations have been lost from side canyons off of the lake that are not impacted directly by inundation. Currently, seven leopard frog populations are known to occur in side canyons of Lake Powell, concentrated around the Escalante River area of the lake. The status of the species at some sites is uncertain. Earlier surveys found frogs as far upstream as Dark Canyon, near Hite, but none have been seen there recently. A small population in Wilson Creek off the San Juan River area of the lake has not been seen since 1994.

The predam distribution of northern leopard frogs in the Grand Canyon reach of the Colorado River is unknown because of the lack of early surveys. Compilation of reports from more recent surveys shows that northern leopard frogs occurred at least as far downstream as Cardenas Creek (RM 71) along the river corridor and in side canyons as far as Bright Angel Creek and Kanab Creek. In spite of intensive searches of potential habitat along the river and in side canyons with perennial streams, the only known remaining population is at a spring-fed marsh between Glen Canyon Dam and Lees Ferry. This population was discovered in 1992 (Drost and Sogge, 1993) and has experienced wide year-to-year fluctuations in numbers. The most recent surveys indicate a sharp decline in population size, with only two adult individuals found in 2004. Marsh vegetation at the site has become very dense, reducing areas of open water, and this reduction may be an important factor in the decline of this population.

Although survey work is continuing, it is clear, based on the historical record, that there has been a severe contraction of the northern leopard frog's range in both Glen Canyon and Grand Canyon. A major concern for remaining populations of frogs is that most or all of them are now effectively isolated from each other. No other extant populations have been found along the river below Glen Canyon Dam, so the population below Glen

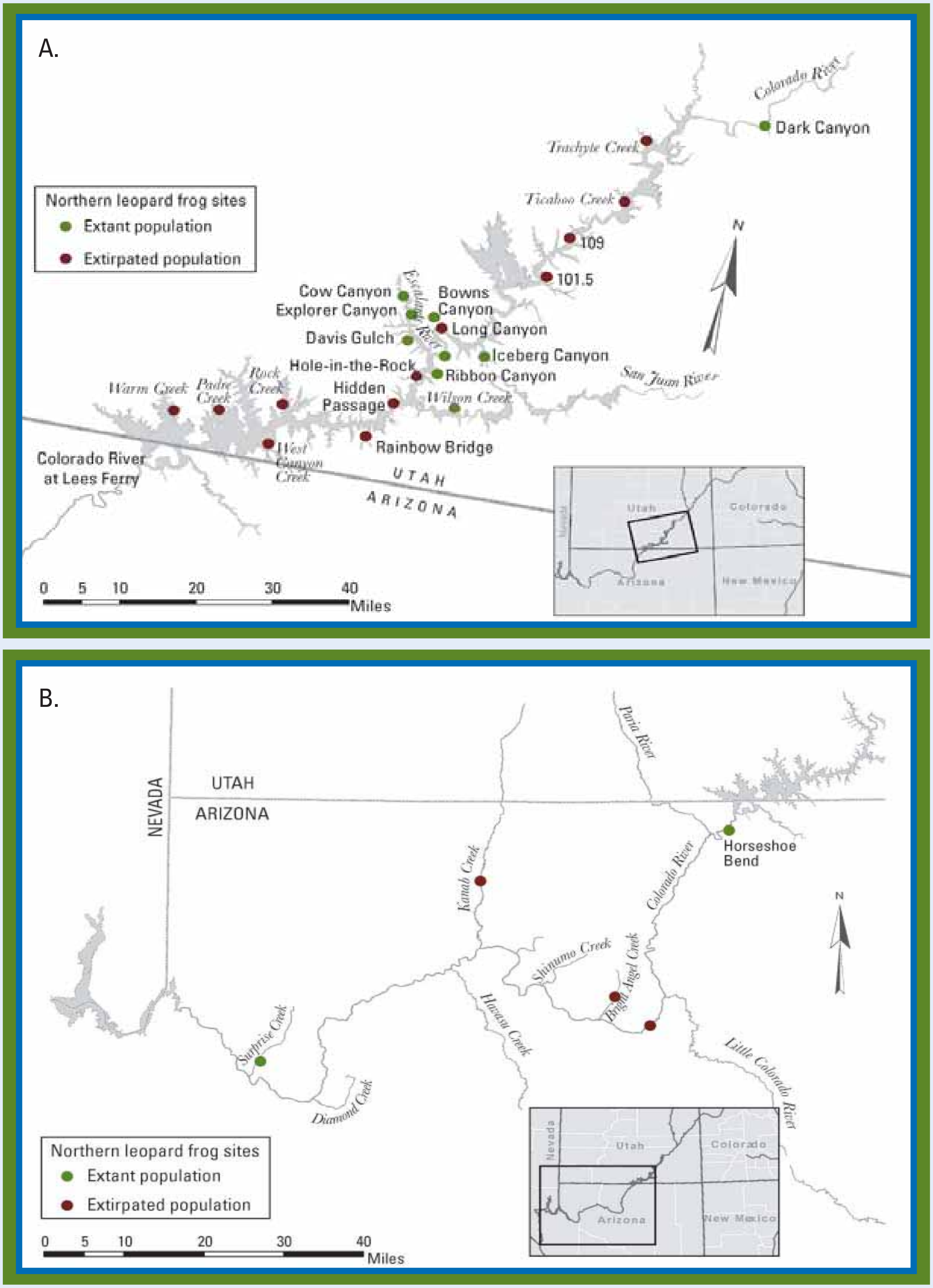


Figure 2. Northern leopard frog (*Rana pipiens*) sites in Glen Canyon above Glen Canyon Dam (A) and the corridor of the Colorado River and its tributaries below Glen Canyon Dam (B). Northern leopard frog numbers have declined substantially, paralleling losses reported in other areas of Western North America. Leopard frog populations have disappeared from 70% of sites where they were formerly found and have declined in numbers at some sites where they still occur.

Canyon Dam is completely isolated. In addition, no frogs have been found along the shores of Lake Powell. The combination of deep lake waters, lack of vegetation cover, and large numbers of predatory fish in the lake probably prevents any movement of frogs among side canyons.

One unexpected, positive finding of the surveys was the discovery of a previously unknown population of a second leopard frog species in western Grand Canyon. In spring 2004, small numbers of leopard frogs were found in a pool in Surprise Canyon (RM 248) (Gelczis and Drost, 2004). The frogs are clearly different from the northern leopard frogs found farther upstream. Genetic studies of the population are still in progress, but the frogs are apparently the lowland leopard frog (*Rana yavapaiensis*). This location represents a significant northward extension in range for this relatively rare species. There are potential threats at the site in the form of nonnative predatory fish and crayfish, but this new population appears to be healthy and thriving.

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